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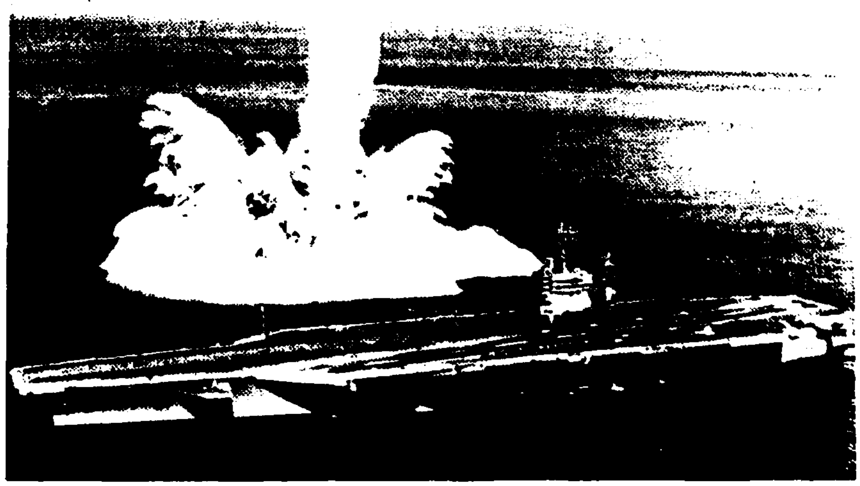

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Shock damage to hull-mounted sonar transducers and related components caused by exploding ordnance is of great concern to the Navy. Consequently, sonar transducers are explosive shock tested at the West Coast Shock Facility, Hunters Point, San Francisco. A conical shock tube is being developed at NRL-USRD as an inexpensive alternative to the WCSF test. The shock tube is a water-filled, conical-bore tube about 8-m long with a 50-cm ID at the large end. Operating parameters are being determined by using an existing small conical shock tube. The conical geometry is chosen because it represents a small solid angle segment of the spherically expanding field in open water. The charge is reduced by the fraction of a sphere represented by the solid angle. The transducer under test is mounted to a piston in the cylindrical chamber at the large end of the tube. The resulting shock wave propagates down the conical tube, strikes the transducer, and produces the pressure shock. The expanding gas bubble then accelerates the piston along its tube, resulting in inertial shock. Extensive testing was performed in a prototype tube to determine proper breech design and amount of explosive needed to reproduce levels in tests at WCSF.

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THE SHOCK TEST FACILITY AN EXPLOSIVE-DRIVEN, WATER-FILLED CONICAL SHOCK TUBE

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Shock damage to hull-mounted sonar transducers and related components caused by exploding ordnance is of great concern to the Navy. Consequently, sonar transducers are required to survive an explosive shock test presently performed at the West Coast Shock Facility(WCSF) at Hunter's Point, San Francisco, CA. A conical shock tube is an inexpensive alternative to the WCSF test. Such a shock test facility being developed at NRL-USRD. The shock tube is a water-filled, conical-bore tube about 8 m long with an inner diameter of 50 cm at the large end.

A small conical shock tube constructed previously is being used to determine operating parameters required for the design of a full scale shock tube. The conical geometry has been chosen because it represents a small solid angle segment of the spherically expanding field in open water. The charge required to produce a specified shock-wave pressure in open water is reduced by the fraction of a sphere represented by the solid angle. The transducer under test is mounted to a piston located in a cylindrical chamber at the large end of the shock tube. The shock wave resulting from the explosive propagates down the conical tube and strikes the transducer, producing the pressure shock. The expanding gas bubble from the explosive then accelerates the piston along its tube, resulting in an inertial shock . Extensive testing was performed in the prototype shock tube to establish a proper breech design, and to determine the amount of explosive needed to reproduce the levels of shock in tests at WCSF. A comparison of the pressure-shock waveforms and the resulting displacements obtained at WCSF and in the prototype shock tube is presented. A design of the full-scale shock tube is also shown.

INTRODUCTION

Naval sonar transducers and related components mounted on the hulls of surface ships and submarines are subjected to both inertial shock and acoustic pressure shock waves when an ordnance charge explodes underwater near the vessel. The potential damage and loss of capability is of great concern to the Navy. As a consequence, naval sonar transducers are required to survive an appropriate test performed presently at the West Coast Shock Facility (WCSF) at Hunter's Point, San Francisco, CA. In this test, the transducer is attached to the bottom of a Floating Shock Platform (FSP) and test charges are detonated near the platform in a prescribed series[1]. The transducers are calibrated both before and after the test to evaluate their susceptibility to shock damage. The tests at Hunter's Point are expensive. In addition, environmental restrictions have led to a reduction in the number of tests that can be performed. Shock testing machines are available for testing equipment weighing up to 7,400 lb. However, these shock machines can apply only inertial shock to the equipment under test. The acoustic shock wave cannot be simulated using these machines. Hydrodynamic shock machines are available[2] to apply a pressure pulse to a device under test. However, these machines produce a slowly varying pulse devoid of the high-frequency spectral content of the pressure shock wave, and the inertial component of the shock is absent. An inexpensive alternative to the Hunter's Point test has become increasingly desirable.

A closed-chamber shock test facility is being developed at NRL-USRD to satisfy this need. Our intention has been to develop a shock tube of adequate diameter to allow the most commonly-tested sonar transducers to be evaluated. Small-diameter shock tubes of this type have been previously described[3], but have been used principally as objects of study. This tube design allows exposure to both shock-wave pressure and inertial shock in a single test by mounting the transducer on a piston which moves in a reaction chamber. The shock-tube dimensions and charge weight are chosen to closely simulate both the peak shock-wave pressure and the FSP's inertial motion during Shot 4 of the heavyweight shock test schedule of reference 1.

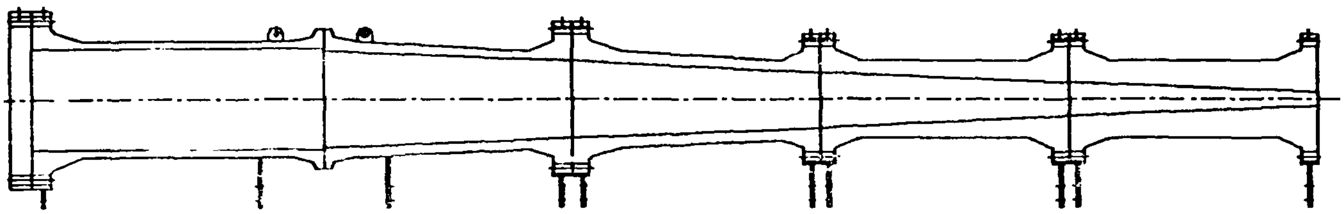

Fig. 1. Full-scale shock tube design.

The shock tube is a water-filled, conical-bore tube about 8-m long with an inner diameter of 50 cm at the large, or nuzzle, end (Fig. 1). Fabrication cost effectively limits the chamber size to 50 cm, which is sufficient for mounting a (size of transducer) at angles of up to 50 degrees. The environmental constraints of operating such a shock tube are minuscule compared to the practice of detonating 60 lb of high explosive in an urban estuary, as must be done at WCSF. Shock tube ests can be performed with a frequency limited only by the mechanics of opening, loading and filling the tube. In operation, he tube is mounted horizontally and a small explosive charge (5-20 gm TNT equiv.) is detonated in the breech, or small diameter end of the tube. This produces the pressure shock wave, which quickly travels down the tube. The transducer under test is mounted on the face of a piston free to slide in a cylindrical chamber, and forms the termination of the tube. After the shock wave strikes the transducer, the expanding gas bubble from the explosion accelerates the piston into the chamber, applying the inertial shock to the transducer.

EXPERIMENTS

A small (15-cm diameter, 3-m length) conical shock tube (Fig. 2) which was built and used in previous experiments s being employed to determine various operating parameters required in the design of the full-scale shock tube.

Filler[3] showed shock wave pressure records that have high-frequency energy of broad spectral range superimposed on the exponential pressure decay of the shock wave. This feature seems to be a characteristic of the shock wave generated in a conical tube with thick steel walls. A potential secondary pressure pulse resulting from the reflection of the shock wave from the piston surface may be absorbed sufficiently by covering the piston surface with a water-soaked cypress wood cap of the proper grain orientation[4]. A typical sample of a shock-wave pressure measurement made in the closed tube and recorded with a 1/4-in diam. tourmaline disk gage s shown in Fig. 3. The gage output was recorded on a digital waveform recorder. The estimated peak pressure obtained for this shot, which was generated from an electric blasting cap of 0.65-gm TNT equivalent, is 2380 psi. The high-frequency energy has a strong

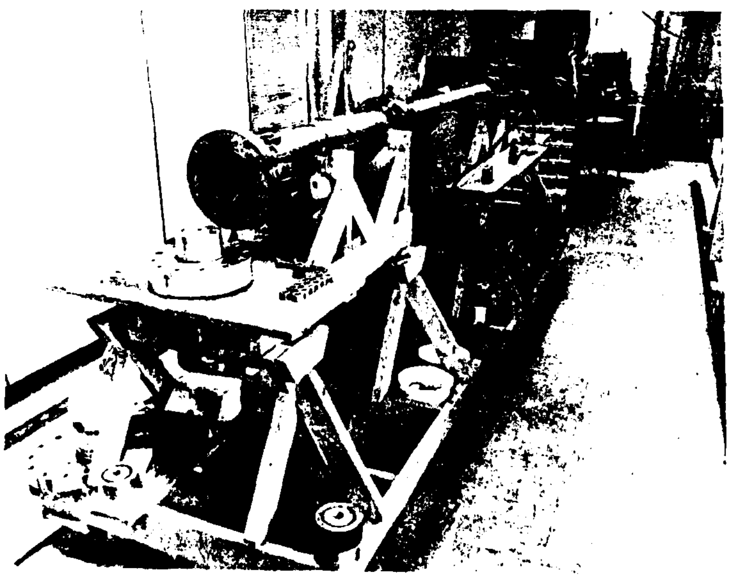

Fig. 2. 15-cm diam. shock tube.

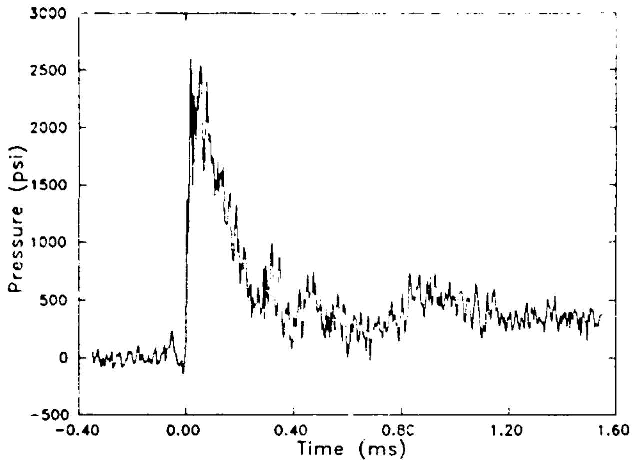

Fig. 3. Shock-wave pressure measurement from 15 cm tube.

visual effect on the appearance of the pressure-wave signature, but does not contribute much to the total energy in the spectrum. This signature may be compared with one recorded similarly at WCSF at a 30-ft standoff test (Shot 3 of MIL-S-901D), seen in Fig. 4.

The inertial shock motion of our reaction chamber piston was recorded by attaching the core of a 20-in linear variable differential transformer (LVDT) to the rear of the sliding piston. It was assumed that the mass of the piston and the water in the tube would be controlled by the spring rate of the gas bubble generated in the explosion. The period of this oscillator was adjusted by adding mass to the piston. Fig. 5 shows the time history of the piston displacement when the tube is driven by a charge consisting of an E-1A blasting cap and 0.7 gm of DuPont Detaprime GA. The piston was loaded with approximately 200 lb of lead. The inertial shock motion of the WCSF FSP has been reported previously[5], and is taken to be a half-sine pulse of approximately 600-ms duration and 16-in peak displacement. The vertical kickoff velocity for the FSP has been computed as 10.7 fps. This agrees quite well with the reported waveform.

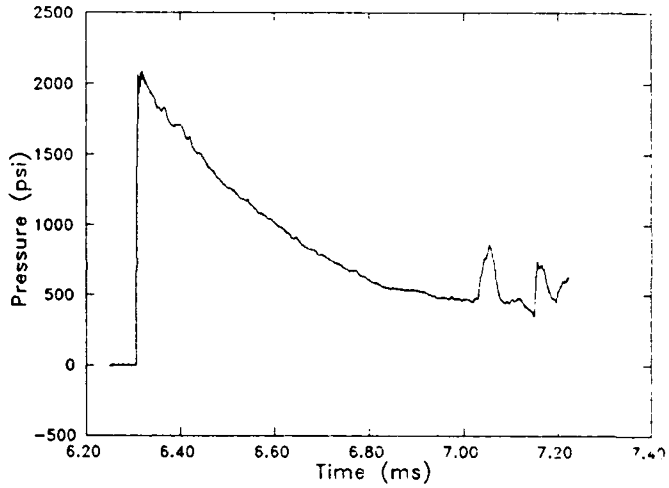

Fig. 4. Shock wave pressure at FSP.

Certain problems that arose during the experimentation have solutions that, at best, consist of compromises. The problem of initiating the charge in a safe and convenient manner still remains. Openings at the breech end of the tube made to admit firing wires erode rapidly and also form stress concentrations. At present, we are running firing lines down the length of the tube, where they can be brought out on standard connectors, but must be replaced for every shot. The breech is designed with a removable block, which is in the form of a steel cylinder with a cavity on one face to hold the explosive. An extensive study was done to find the best design and the most cost-effective material for this block. Titanium proved the most durable material, but AISI 1018 steel is the choice when the breech block can be replaced frequently. Another problem is the vibration that couples into the steel tube that then reradiates as sound into the water. This effect is what causes the shock wave pressure signature to appear "noisy". Normally, we estimate the peak pressure level by the method descibed by Cole[6], but the additional "noise" signal on the decay portion of the curve makes the extrapolation procedure less exact. We were able to reduce the "steel" portion of the signal somewhat by mechanically isolating the tube flanges and breech block with elastomeric gaskets, but this greatly increased the frequency of blowouts and leaks. Finally, the problem of corrosion strongly affects the choice of material for the tube itself. Nickel-aluminum bronze with integrally-cast flanges is the material of choice from the point of view of strength and corrosion resistance, however the cost is prohibitive. Using welded-on steel flanges lowers the cost to an acceptable range, but creates unsolvable manufacturing difficulties. The best compromise, considering all factors is stainless steel 316L with integrally-cast flanges.

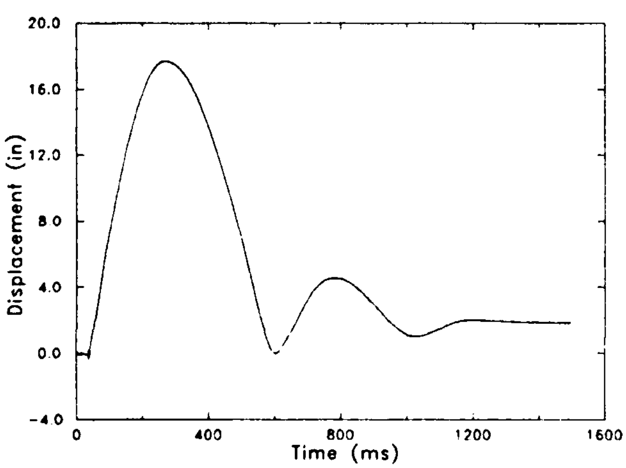

Fig. 5. Reaction block motion in 15 cm tube.

CONCLUSION

We have proposed a design for a full-size shock tube facility that will provide either alternative testing or pre-qualifying test results to the WCSF MIL-S-901D compliance. As many as four test cycles per work day may be carried out, and at a fraction of the cost per test.

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